Abraham Castaneda (Assembly, Design overview/Illustration, MATLAB Simulations)
Daniela Nikoloska (Parts, Assembly, Introduction)
Maxwell Stonham (Assembly, Conceptual Theory, Results, Math Theory)
Dylan Cazares (Assembly, LTSPICE Simulations, MATLAB Simulations)
Edreese Basharyar (Assembly, Conceptual Theory, Math Theory)

The Reusable Sparker: A Shocking Experiment

Introduction

The objective of this project is to design a reusable sparker using electrostatic principles and raw household products. It is common knowledge that a spark can be created when one shuffles their feet on carpet or rubs a balloon on their head then touches metal. This concept is known as static electricity and is one of the oldest scientific phenomena known to man. Static electricity is essentially the interactive force between negative and positive charges. A static electric spark occurs when the dielectric between differently charged objects breaks down. Creating the spark itself is simple; however, a reusable sparker device requires more than simply a carpet and balloons. In order to create a sparker, an electrical charge must be produced and stored. We recreated a device known as the Leyden jar to act as our dielectric capacitor. The Leyden jar was first invented in the mid 1700's by the German physicist, Ewald G. Von Kleist, and Dutch scientist Pieter Van Musschenbroek. An early form of the jar was composed of a glass flask filled with water and held in the hand of an assistant. One end of a wire was dipped into the water and the other to an electrical machine. The assistant would then touch the wire with their hand leading into the jar and receive a shock. One of the main hurdles for this project, however, was to create such a machine with household materials, which required a deeper understanding of the phenomena at play.

Theory

Conceptual Understanding

To understand the phenomena that occurs in this experiment, we recall Coulomb's Law, which states that like charges repel while unlike charges attract, given that the polarity of charges may be positive or negative. We also recall the triboelectric effect, which is the electrification of two different materials by method of contact such as rubbing two materials together in a process called triboelectrification.

To be able to build up charge, we first rub a PVC pipe with a towel; when these two objects are rubbed together, the towel starts to give up its electrons and is eventually positively charged. This allows the PVC pipe to collect all of the electrons, which makes the PVC pipe negatively charged overall. As we are rubbing these objects together, we are doing it near the top of our leyden jar, where we have a ball wrapped around in aluminum foil. Due to the conductivity of the aluminum, the extra electrons from the PVC pipe will transfer to the top of our leyden jar. The electrons will continue to flow down into the center of the jar, since we have a metal wire that is placed from the top to the middle of the jar. In the jar itself, we used saltwater, which is simply made by dissolving salt (sodium chloride) into pure water. This is much more conductive than pure water due to the amount of ions, and allows the current to flow from the wire to the water.

Consequently, all of the electrons inside of the leyden jar will attract the positive charge on the exterior foil (which is neutral). This attraction takes place between the dielectric (jar) which then stores energy in an electric field between the jar. By touching the two balls together, this allows a neutralization to take place between the two conductors as the electrons from the negatively charged ball jumps to the neutral ball connected to the exterior foil which causes the spark since the voltage between becomes high enough to break down air.

Mathematical understanding

In order for us to measure the voltage of our spark in this experiment, we need to determine the dielectric strength of air. Air is considered a good dielectric having a dielectric strength of 3kV/mm. This means that 3kV/mm is the maximum electric field air is able to withstand before undergoing electric breakdown. Electric breakdown occurs when a high enough voltage is applied within a dielectric that allows it to become partially conductive so long as the voltage exceeds the dielectric strength.

When doing our experiment, we produced a spark at approximately 1 mm between the two balls. Knowing that the dielectric strength of air is about 3kV/mm, we can assume that we were able to create a potential difference across the two balls of approximately 3kV at the time of the spark.

Our values for the jar is shown as:

- r = 41.5mm (radius)
- h = 153mm (height/length)
- d = 0.89mm (thickness of jar)

We can also calculate the capacitance using the formula shown below:

$$C = \frac{Q}{V} = \frac{2\pi\varepsilon L}{\ln\frac{b}{a}}$$

- C = capacitance
- L = 153mm (length of jar)
- b = 41.5mm (radius of jar to the external surface)
- a = 40.61mm (radius of jar to the internal surface)
- ε = [permittivity of free space * dielectric constant]

We know that the dielectric constant of plastic is about 3.5 while the permittivity of free space is $8.85\text{x}10^{-12}$. Calculating the total permittivity, we get approximately $4.489\text{x}10^{-7}$.

Plugging these values into Matlab, we get an approximate capacitance of 1.374nF. When we measured the capacitance on a multimeter, we got a value of about 1.41nF, which is very close to our theoretical calculation.

We can also approximate a value for charge required for the spark to be produced. Using a voltage value of 3000V and our capacitance value of 1.374nF, plugging it into Q = C*V, we get a value of 4.12uC.

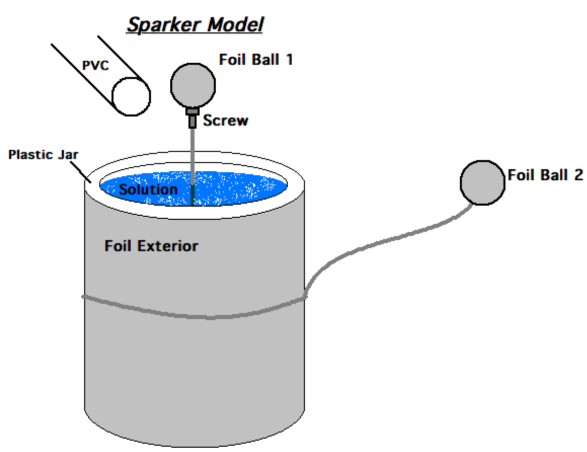
Design Overview

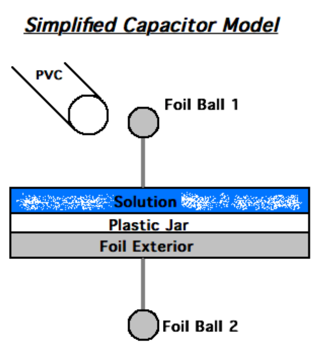
Our sparker design draws on the capacitive properties of a leyden jar, which is a jar made out of Polyethylene Terephthalate, or polyester plastic, that has a diameter of 83mm, height of 153mm and a thickness of 3mm. Aluminum foil is wrapped around the outer surface of the jar where the inside of the jar is filled with a salt water solution. The salt water acts as part of the electrodes where the other electrode is the surface of the jar wrapped with aluminium foil and the plastic jar acting as the dielectric layer. This capacitor is responsible for storing the charge necessary to create a spark.

Attached to each electrode of the leyden jar was a ping pong ball wrapped in aluminum foil. The foil wrapped ping pong ball attached to the salt-water solution (which will be referred to as ball 1) was secured by taping the excess foil around the ball to a nail which was inserted into the jar's lid. To make sure that ball 1 would conduct the charge to and from the salt-water solution, a wire was wrapped around the nail and placed directly into the solution. As for the ball attached to the outer electrode (which will be referred to as ball 2), a wire was wrapped around the aluminum foil surface of the leyden jar and taped to the excess foil that was wrapped around the ping pong ball. This outer electrode ball extension would be the only movable component of the sparker, which would allow the user to manipulate the distance between ball 2 and ball 1. These 2 conductive foil balls would act as the electrode extensions through which the accumulated charges would discharge when brought close together.

Needless to say, safety measures are needed to be taken in order to prevent the discharge from making contact with the user operating the sparker. As a precaution, extra electrical tape was wrapped around the wire attached to ball 2, which the user would be able to hold onto while manipulating ball 2 without making contact with any conductive material.

The charges in question would be introduced to the leyden jar through ball 1 (). When sufficient charge has been introduced (20 rubs often makes for a reasonably large spark), all the user needs to do to create the spark is bring ball 1 and ball 2 within 1 mm from each other.





Results

Edreese starts by rubbing the PVC pipe with a towel multiple times to build up static electricity which causes an imbalance between negative and positive charges. He then proceeds to stroke the pipe near the aluminium ball that connects the nail and wire into the salt solution inside the jar that Abraham is holding which builds up negative charge on the ball and inner surface of the jar. An interesting observation is that during his stroking, we notice small noises being produced; this is due to the air breaking down from the static electricity being produced. After about 20-40 strokes, Abraham safely moves the wire connected to the exterior of the jar via the insulated part of the wire to prevent himself from getting shocked and moves the exterior ball to the ball connected to the inner ball; this produces a spark at about a distance of 1 mm. See Figure (2) in the appendix.

Appendix

Figure 1: Group 1, with members (from left to right) Maxwell S, Abraham C, Dylan C, Edreese B, and Daniela N.

Figure 2: A spark from our reusable sparker

```
clc
clearvars

Radius = 0.083./2
Height = 0.153
Thickness = 0.00089
Jar = [Radius Height Thickness]
k = 3.5 % Dielectric constant
eo = 8.85.*10.^-12 % Permivitivty of free space
e = eo.*k % Permivitivy of PET Plastic
C = (2.*pi.*e.*Jar(2))./(log(Jar(1)./(Jar(1)-Jar(3))));
Capacitance = abs(C)


Radius =

    0.0415


Height =

    0.1530


Thickness =

   8.9000e-04


Jar =

    0.0415    0.1530    0.0009
```

```
k =
```



```
    3.5000


eo =

   8.8500e-12


e =

   3.0975e-11


Capacitance =

   1.3735e-09
```

Calculating Charge Necessary for Sparkage

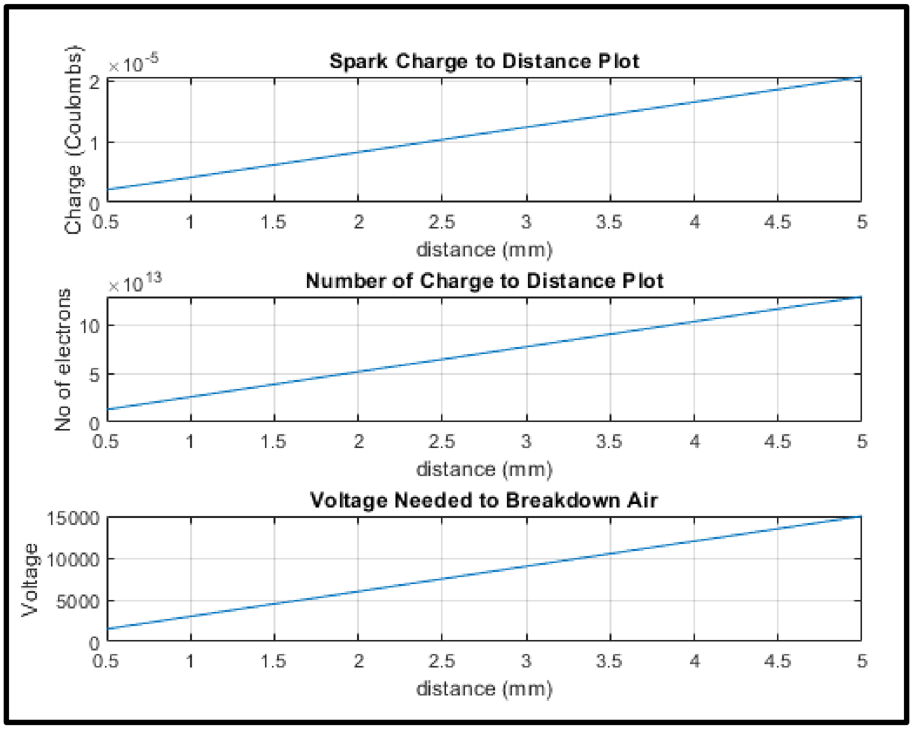
Using our calaculated capacitance value and the dialectric strength of air, we can determine the charge necessary to create a spark at varying distances.

```
C = abs(C); % Capacitance
V = 3000; % Voltage
d = [0.5:.5:5]; % Distance
Q = C.*V.*d; % Charge Needed at Different Distances
N = Q./(1.602.*10.^-19); % Number of Electrons
Volt = V.*d; % Voltage Breakdown of Air

figure(1)
subplot(3,1,1)
plot(d,Q)
title('Spark Charge to Distance Plot')
xlabel('distance (mm)')
ylabel('Charge (Coulombs)')
grid on

subplot(3,1,2)
plot(d,N)
title('Number of Charge to Distance Plot')
xlabel('distance (mm)')
ylabel('No of electrons')
grid on

subplot(3,1,3)
plot(d,Volt)
title('Voltage Needed to Breakdown Air')
xlabel('distance (mm)')
ylabel('Voltage')
grid on
```



Figures 2-5: Code and results from MATLAB simulations, which were used to find the capacitance of the device as well as the charges, electron count, and voltage necessary to generate a spark.

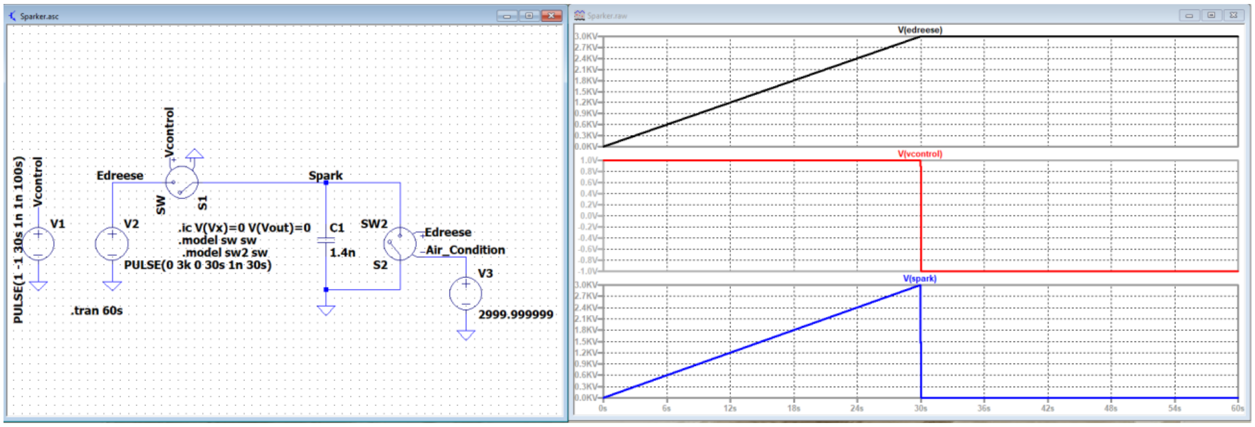


Figure 6: LTSPICE Simulation emulating the discharge of the capacitor. Edreese charges the capacitor with a voltage via the triboelectric effect until the 30 second mark (hypothetically he stops rubbing the PVC pipe at this point). Right when the voltage across the capacitor reaches 3kV, the switch closes, which represents the air breaking down at 3kV (distance is assumed to be 1mm at this point). As we can see, the capacitor's voltage upon being shorted to the opposite electrode becomes 0 (the capacitor is grounded by the person holding the sparker in our experiments). This discharge causes the spark to occur.